10/575129

IAP20 Rec'd PCT/PTO 07 APR 2006

Surface with reduced particle deposition and reduced ice formation

Description

The invention relates in general to surfaces along which media, e.g. gases, liquids or multi-phase mixtures are flowing, especially to a device for transportation of a flowing medium and/or for heat exchange between a flowing medium and the device and also to the application of such devices.

Surfaces along which media are flowing play a role in many technical areas and in a variety of applications.

From EP 92 911 873.5, PCT RU92/00106 und EP 96 927 047.9, PCT/EP96/03200, surfaces with a special three-dimensional surface structure are known, where the process when a continuous medium like a gas, a liquid or a two-phase mixture flows along the surface is accompanied by self-organization of secondary twisted tornado-like jets originating on the surface and flowing out of it into the parent flow.

It is further known that friction could be reduced by means of the self-organizing secondary vortices and that in addition heat transfer between the surface and the streaming media, e.g. gases, liquids and two-phase mixtures containing gases and liquids could be increased.

A problem which often arises when media are flowing along a surface is the deposition of particles on the surface. An example for this is the transport of oil through a pipeline. Due to the deposition of particles on the inner surface of the pipeline time-consuming and costly cleaning becomes necessary.

In air-conditioning systems a heat exchange takes place between a surface and a medium, which flows along the surface. The problem here is especially that of ice formation on the surface. This problem for instance arises in air-conditioning systems of commercial aircrafts, where only small amounts of fresh air are supplied and the air therefore has a high moisture content.

Therefore it is an object of the invention to show a way how the deposition of particles and/or the formation of ice on a surface, along which a medium flows, can be reduced.

The object of the invention is achieved in a surprisingly simple manner by a subject matter of one of the attached independent claims. Advantageous embodiments and refinements are defined in the respective dependent claims.

The inventors surprisingly found that the formation of secondary vortices on surfaces with a special three-dimensional surface structure as described in EP 92 911 873.5, PCT RU92/00106 and EP 96 927 047.9, PCT/EP96/03200 also has the effect that particles are moved away from the surface, thereby reducing the deposition of particles and the formation of ice.

Accordingly, an inventive device for transport of a flowing medium and/or for heat exchange between a flowing medium and the device comprises at least one surface having a plurality of dimples.

In a preferred embodiment of the invention the dimples are arranged periodically on the surface.

In another preferred embodiment of the invention the centers of three adjoining dimples form an equilateral triangle, the distance between the centers of two neighboring dimples and the distance between two rows of dimples each having a constant value.

Preferably the dimples have a two-dimensional edge as a boundary and with advantage the dimples are rounded at the edge towards the remaining surface.

Such a geometry of a surface especially improves the flow properties with respect to friction resistance as also with respect to heat and mass transfer for surfaces, along which a medium flows, which consists of a gas, a liquid, a two-phase mixture, or a mixture of multiple phases.

The underlying principle are secondary vortices, which originate in the dimples and lead to an organized transportation of medium from the surface to the main flow. Due to the reduced pressure inside the vortex flows the boundary layer is sucked in, so that the thickness of the boundary layer does not increase.

Advantageously the dimples essentially have the form of a section of a sphere or an ellipsoid.

Further forms and arrangements of dimples are disclosed in the applications EP 92 911 873.5, PCT RU92/00106 and EP 96 927 047.9, PCT/EP96/03200, which are completely incorporated here by reference.

Accordingly the form and arrangement of dimples can be expressed by the equation

$$r(\varphi,z)=\left(\frac{z}{h}\right)^{k}\left[r(h,0)-\frac{l_c}{2}+\Delta r\left(\frac{\varphi}{180}-\frac{1}{4\pi}\sin\frac{4\pi\varphi}{180}\right)+\right.$$
$$\left.+A_1\Delta r\left(\sin\frac{\pi\varphi}{180}-\frac{1}{3}\sin\frac{3\pi\varphi}{180}\right)+A_2\Delta r\left(\sin\frac{2\pi\varphi}{180}-\frac{1}{2}\sin\frac{4\pi\varphi}{180}\right)\right],$$

wherein the parameters of the equation can be chosen differently depending on the type of medium, the form and dimensions of the transport channel, the flow velocity, the temperature of the medium and of the surface and further factors.

With advantage the device is provided with at least one transport channel, wherein the at least one surface, which has a plurality of dimples, is provided as the inner surface of said transport channel.

Preferably the at least one surface is provided such that in the proximity of the surface vortices are formed in the medium, when the medium flows along the surface. In this way the forming of flows in certain directions in the vicinity of the surface is promoted, leading to a transportation of particles away from the surface, thereby

reducing the deposition of particles and the formation of ice as compared to a flat surface.

The problem of ice formation especially arises when a medium is to be cooled, like for instance in an air-conditioning system. When in an air-conditioning system for cooling a medium, the medium is led through a flow channel, ice formation on a flat surface increases towards the end of the channel, i.e. the more the medium is already cooled while flowing through the flow channel. Experiments performed by the inventors showed that when using a flow channel, which comprises an inner surface with a plurality of dimples according to the invention, the increasing ice formation towards the end of the flow channel is reduced. Furthermore, in the area of the dimples themselves, from which the vortices start, a clearly reduced ice formation could be observed in comparison with the remaining surface.

Therefore, it is especially advantageous to use a device according to the invention in an air-conditioning system. Due to the reduced ice formation the availability and reliability of an air-conditioning system can be improved.

The invention further proposes a surface, which comprises dimples, wherein the edges of said dimples are rounded, thereby forming a central dimple area and at least one curvature area for each dimple, which continuously connects the dimple to the surrounding surface.

Preferably said central dimple area essentially has the form of a section of a sphere or an ellipsoid.

With great advantage said curvature area of the surface comprises at least a first curvature area and a second curvature area, the first curvature area having a different curvature than the second curvature area. Preferably said first curvature area is rounded with a first rounding radius and said second curvature area is rounded with a second rounding radius.

For certain applications a surface comprising dimples having a relatively low depth in relation to the diameter is preferable. In this regime it can be of special advantage to combine two different, consecutive curvature areas to realize different sizes of the central dimple area.

Also two curvature areas are very advantageous in order to achieve a gentle transition from the dimple to the surrounding surface, thereby reducing the probability of destruction of the advantageous secondary vortices, which originate in the dimples.

With advantage the dimples are arranged periodically on the surface. In order to realize a good coverage of the surface, the centers of three adjoining dimples preferably form a triangle as described above. The maximum coverage can be reached in this kind of arrangement when the curvature areas of said three adjoining dimples are in contact with each other. Even in this arrangement a small area of flat surface remains in the center of three respective adjoining dimples. In this location preferably additional smaller-sized dimples are provided, by which the flow properties can be further improved.

Further a device for transportation of a medium lies within the scope of the invention, which comprises at least one surface with dimples as described above. With advantage the surface with dimples is provided as an inner surface of a transport channel, in particular a pipe, of the device, in which the medium is transported. The implementation in such a device is of advantage due to a further result of the described surface structure found by the inventors, consisting in a reduced deposition of particles on the surface compared to a flat surface.

Further a device for heat exchange between a flowing medium and at least one surface of the device, in particular an air-conditioning system or part thereof, is proposed, wherein the at least one surface is provided with dimples. Here it can be taken advantage of the effect of reduced ice-forming on a surface, which comprises the described dimples, in comparison to a flat surface.

Also a layer or coating for applying on a surface is proposed, which comprises a surface with the described dimples. By use of such a layer, a device having a surface along which a medium flows can be upgraded for improved flow properties, such as reduced friction resistance or improved heat or mass transfer or a combination thereof.

For this purpose the layer can advantageously be provided with a first side and a second side, wherein said first side comprises dimples as described above and said second side comprises a self-adhesive coating.

Accordingly the invention proposes a method for producing a surface with reduced particle deposition and/or reduced ice formation and/or reduced friction resistance and/or improved heat exchange with a surrounding medium, comprising the step of applying a described layer onto said surface.

Also a method is proposed for producing a surface with reduced particle deposition and/or reduced ice formation and/or reduced friction resistance and/or improved heat exchange with a surrounding medium, which comprises the steps of

- providing a workpiece with at least one surface and
- imprinting into said at least one surface a structure comprising dimples.

Another inventive method for producing a surface with reduced particle deposition and/or reduced ice formation and/or reduced friction resistance and/or improved heat exchange with a surrounding medium, comprises the steps of

- providing a casting mold with at least one structured surface and
- molding, in particular injection molding, of a workpiece with at least one surface comprising dimples by means of said casting mold.

The invention is not limited to the described production methods, but shall also encompass any other method, which is suitable to produce a surface comprising the above described dimples.

Also within the scope of the invention lies the usage of a surface with dimples as described above as a surface of a

device for transportation of a medium or a device for heat exchange, in particular the usage of such a surface as a surface of a flow channel for reducing particle deposition and/or ice formation, when a medium flows along the surface.

The invention further proposes an air-conditioning system for cooling a heat exchange medium, comprising at least one flow channel for the heat exchange medium, wherein the inner surface of the flow channel is provided with a plurality of dimples.

In the following the invention is described exemplary in more detail on the basis of preferred embodiments and with reference to the enclosed drawings. Therein same reference marks in the drawings indicate same or similar parts.

<u>Brief Description of the Figures</u>

It is shown in:

Fig. 1: a schematic diagram of a preferred embodiment of an inventive device,

Fig. 2: a schematic diagram of a first distribution of dimples,

Fig. 3: a schematic diagram of a central cross section through a dimple of Fig. 2 perpendicular to the surface,

Fig. 4: a schematic diagram of a second distribution of dimples,

Fig. 5: a schematic diagram of a cross section through a dimple according to a second preferred embodiment.

An inventive device can be provided for instance as a pipe 1 as shown in Fig. 1, the inner surface 2 of which pipe 1 having a regular structure of dimples 4 with a two-dimensional edge 3 as boundary. This pipe can be utilized as a transport channel for transportation of a medium. The significant improvement achieved by using the inventive surface in this embodiment lies in a reduced deposition of particles on the surface due to the suction of the boundary layer from the surface into the main flow by means of the self-organizing vortex flows originating in the dimples.

Furthermore, because of the same reasons the forming of ice on the surface is reduced, so that such a pipe can also be utilized with great advantage in a device, in which a medium is to be cooled, like an air-conditioning system, especially an air-conditioning system used in an airplane.

Fig. 2 shows schematically a preferred distribution of dimples 4 on a flat surface. The dimples 4 are arranged periodically, wherein the centers of three directly adjoining dimples 4 form an equilateral triangle. The angle α therefore has a value of 60°. The distance between the centers of two adjoining dimples 4, which is equal to the length of a side of the triangle, has a constant value t_2. The distance between two rows of dimples 4, which equals the height of the triangle, has a constant value t_1. The parameters t_1 and t_2 can have different values depending on the purpose for which the surface shall be utilized. The dimples 4 and the remaining surface are separated by the edges 3.

Fig. 3 shows a cross section through the center of a dimple perpendicular to a flat surface. In this embodiment the dimple essentially has the form of a calotte with radius R_1, height h and diameter d, which is rounded at the edges with a rounding radius R_2. Thereby in this example the dimple is symmetrical with respect to rotation around an axis through the center of the dimple and perpendicular to the surface.

Fig. 2 and Fig. 3 show an example of form and arrangement of dimples on a flat surface, which is shown in Fig. 1 deformed to form a pipe. Depending on several parameters, as for instance the type of medium, the form and dimensions of the transport channel, the flow velocity and the temperature of the medium and of the surface, various other forms and arrangements of dimples also lie within the scope of the invention.

Fig. 4 shows schematically a top view of a distribution of dimples comprising a central dimple area 110, a first curvature area 120 and a second curvature area 130, the named areas being arranged consecutively from the center of the dimple to the outside.

The central dimple area has a diameter of d_1, the first curvature area has an diameter of d_2 and the second curvature area has a diameter of t_1. The dimples are arranged similar to Fig. 2, but in this preferred embodiment the outer rims of two adjoining dimples are in contact with each other for a maximum surface coverage.

Again, the centers of three adjoining dimples form an equilateral triangle, the distance between the centers of

two adjoining dimples having the constant value t_1 and the distance between two rows of dimples having the constant value t_2. In this embodiment therefore the diameter of the second curvature area equals the distance between two adjoining dimples t_1.

A small area of surface remains in the center between three adjoining dimples. In this location preferably additional smaller-sized dimples 200 can be provided, thereby further improving the flow properties of the surface.

The cross section AA' through the center of a dimple perpendicular to the surface is shown in more detail in Fig. 5.

The central dimple area 110 essentially has the form of a section of a sphere, followed in the outward direction by two consecutive curvature areas. Since the curvature areas can be described as an arc, which is rotated in space, they have a surface formed as a part of a torus or similar thereto.

The form of the central dimple area, of the first curvature area and of the second curvature area in the shown cross section perpendicular to the surface and through the center of the dimple is defined by the following parameters:

d_1: Diameter of the central dimple area,

d_2: Outer diameter of the first curvature area,

t_1: Outer diameter of the second curvature area,

R_1, C_1: Radius and center point of the sphere, the section of which forms the surface of the central dimple area,

R_2, C_2: Radius and center point of the rounding radius of the first curvature area,

R_3, C_3: Radius and center point of the rounding radius of the second curvature area,

P_1: Transition point from the central dimple area to the first curvature area,

P_2: Transition point from the first curvature area to the second curvature area,

P_3: Transition point from the second curvature area to the surrounding surface,

h_1: Difference in height between the lowest point of the central dimple area and the outer rim of the central dimple area,

h_2: Difference in height between the inner rim of the first curvature area and the outer rim of the first curvature area,

h_3: Difference in height between the inner rim of the second curvature area and the outer rim of the second curvature area,

α_1: Angle between the y-axis and a line connecting C_2 and C_3,

α_2: Angle between the x-axis and a line connecting C_1 and C_2,

f: Parameter related to the portion of the surface covered by the central dimple area in relation to the combined area of central dimple area and curvature areas.

There is one point, in which the circle with radius R_1, being part of the sphere that forms the central dimple area, and the circle with radius R_2, defining the curvature of the first curvature area, have a mutual tangent. Further, there is another point, in which the circle with

radius R_2 and the circle with radius R_3 have a mutual tangent.

To completely describe the form of the dimple a set of parameters, in particular the parameters d_1, α_1, α_2, R_2/R_1 and f, are chosen according to the necessities of the specific purpose the surface shall be used for and depending on whether drag reduction or improved heat exchange has priority. For most purposes the coverage of the surface by the central dimple areas lies below 70%, but also a greater coverage falls within the scope of the present invention.

The remaining of the named parameters can be calculated by means of the following equations:

$$R_1 = \frac{d_1}{2 \cdot \sin\alpha_1},$$

$$R_2 = \frac{R_2}{R_1} \cdot \frac{d_1}{2 \cdot \sin\alpha_1},$$

$$R_3 = \frac{t_1 - \frac{d_1}{2} \cdot \frac{R_2}{R_1} \cdot \frac{(1 - \sin\alpha_1)}{\sin\alpha_2}}{\sin\alpha_2},$$

$$h_1 = \frac{d_1}{2} \cdot \frac{(1-\cos\alpha_1)}{\sin\alpha_1},$$

$$h_2 = R_2 \cdot (\cos\alpha_2 - \cos\alpha_1),$$

$$h_3 = R_3 \cdot (1-\cos\alpha_2),$$

$$H = h_1 + h_2 + h_3,$$

$$t_1 = \sqrt{\frac{\pi}{6 \cdot f}} \cdot d_1,$$

$C_1 = (X_{C1}, Y_{C1})$ with $X_{C1} = 0$, $Y_{C1} = R_1 - H$,

$$C_2 = (X_{C2}, Y_{C2}) \text{ with } X_{C2} = \frac{d_1}{2} \cdot \left(1 + \frac{R_2}{R_1}\right), \quad Y_{C2} = R_3 + \frac{X_{C3} - X_{C2}}{tg\alpha_2},$$

$$C_3 = (X_{C3}, Y_{C3}) \text{ with } X_{C3} = \frac{t_1}{2}, \quad Y_{C3} = -R_3,$$

$$P_1 = (X_{P1}, Y_{P1}) \text{ with } X_{P1} = \frac{d_1}{2}, \quad Y_{P1} = H - h_1,$$

$$P_2 = (X_{P2}, Y_{P2}) \text{ with } X_{P2} = \frac{t_1}{2} - R_3 \cdot \sin\alpha_2, \quad Y_{P2} = R_3 \cdot (\cos\alpha_2 - 1),$$

$$P_3 = (X_{P3}, Y_{P3}) \text{ with } X_{P3} = \frac{t_1}{2}, \quad Y_{P3} = 0,$$

said equations being defined in a two-dimensional coordinate-system with the x-axis in the plane of the surface and with the y-axis through the center of the dimple and perpendicular to the surface.